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Physics Letters B

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DØ Collaboration

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ARTICLE INFO

Article history:

Received 7 July 2009

Received in revised form 23 September 2009

Accepted 3 October 2009

Available online 7 October 2009

Editor: L. Rolandi

PACS:

14.80.-j

13.85.Rm

ABSTRACT

A search for pair production of first-generation leptoquarks (LQ) is performed with data collected by the DØ experiment in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV at the Fermilab Tevatron Collider. In a sample of data corresponding to $\sim 1 \text{ fb}^{-1}$ the search has been performed on the final states with two electrons and two jets or one electron, two jets and missing transverse energy. We find our data consistent with standard model expectations. The results are combined with those found in a previous analysis of events with two jets and missing transverse energy to obtain scalar LQ mass limits. We set 95% C.L. lower limits on a scalar LQ mass of 299 GeV, 284 GeV and 216 GeV for $\beta = 1$, $\beta = 0.5$ and $\beta = 0.02$ respectively, where β is the LQ branching ratio in the eq channel. This improves the results obtained with a lower luminosity sample from Run II of the Tevatron. Lower limits on vector LQ masses with different couplings from 357 GeV to 464 GeV for $\beta = 0.5$ are also set using this analysis.

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Leptoquarks are conjectured particles, predicted by many extensions [1] of the standard model (SM). In such exotic models, transitions between the leptonic and baryonic sectors would be allowed. Thereby, the detection of leptoquarks (LQ) could be, among others, the signature of compositeness, supersymmetric couplings in R-parity violating models, Grand Unification models, or technicolor. Leptoquarks can be scalar or vector fields. It is generally assumed that there is no intergenerational mixing, because it is severely constrained by low-energy experiments, and that first-generation LQs couple only to e or ν_e and to u or d quarks. At the Fermilab Tevatron Collider, pair production of leptoquarks can proceed through quark–antiquark annihilation (dominant for $M_{LQ} \geq 100$ GeV) or through gluon fusion, therefore being independent of the LQ – e – q Yukawa coupling λ . Thus the production cross section for scalar leptoquarks only depends on the strong coupling constant and on the leptoquark mass. In the vector leptoquark case, the production cross section also depends on the anomalous couplings κ_G and λ_G of the LQ to the gluon. At the CERN e^+e^- Collider (LEP), pair production of leptoquarks could have occurred in e^+e^- collisions via a virtual γ or a Z boson in the s -channel. Experiments at the Fermilab Tevatron Collider [2,3] and at the LEP Collider [4] set lower limits on the masses of leptoquarks. The H1 and ZEUS experiments at the DESY e^+p collider HERA published [5] lower limits on the mass of a first-generation LQ that depend on the coupling λ . In the case of single LQ production at LEP or at the Tevatron, the mass limits depend also on λ [6]. The branching ratio for LQ or \bar{LQ} decay into a charged lepton and a quark is denoted as β , so $1 - \beta$ is the branching ratio of the reaction $LQ \rightarrow \nu + q$. The branching ratios of the three decay modes $LQ\bar{LQ} \rightarrow eeq\bar{q}$, $LQ\bar{LQ} \rightarrow \nu\nu q\bar{q}$ and $LQ\bar{LQ} \rightarrow \nu\nu q\bar{q}$ are then equal to β^2 , $2\beta(1 - \beta)$ and $(1 - \beta)^2$, respectively.

In this Letter, we present a search for first-generation leptoquarks for two cases: when both leptoquarks decay to an electron and a quark and when one of the leptoquarks decays to an electron and a quark and the other to a neutrino and a quark. The corresponding final states consist of two electrons and two jets ($eejj$) and one electron, two jets and missing transverse energy ($evjj$).

This study is performed on data collected with the DØ detector [7] in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV during Run II of the Tevatron Collider. The DØ detector comprises three main elements. A magnetic central tracking system, which consists of a silicon microstrip tracker and a central fiber tracker, is located within a 2 T superconducting solenoidal magnet. Three liquid-argon/uranium calorimeters, a central section (CC) covering pseudorapidities¹⁰ $|\eta|$ up to ~ 1 and two end calorimeters (EC) extending coverage to $|\eta| \simeq 4$, are housed in separate cryostats. Scintillators between the CC and EC cryostats provide a sampling of developing showers for $1.1 < |\eta| < 1.4$. A muon system is located outside the calorimeters and covers the region $|\eta| < 2$. The luminosity is measured using plastic scintillator arrays placed in front of the EC cryostats. The data samples for the $evjj$ and $eejj$ analyses are selected with combinations of single electron and electron plus jets triggers. The corresponding integrated luminosity is $\sim 1 \text{ fb}^{-1}$.

Electrons are defined as clusters of energy deposition in the calorimeters with a high fraction ($> 90\%$) deposited in the electromagnetic (EM) sections. The energy cluster must be isolated from

other energy deposits in the calorimeter¹¹ and matched with a charged particle with transverse momentum $p_T > 5$ GeV. A condition on the value of an electron likelihood based on a shower shape parameter and conditions on the number of tracks in the vicinity of the electron are applied. Electrons that fulfill all the above criteria except the likelihood condition are classified as *loose* electrons. Those which satisfy all criteria are referred to as *tight* electrons.

Jets are reconstructed with an iterative cone algorithm [8] with radius of 0.5 and a minimal distance $\mathcal{R} > 0.5$ (see footnote 11) from any EM object. The jet energy scale (JES) corrections were derived from the transverse momentum balance in photon-plus-jet events. The missing transverse energy \cancel{E}_T is calculated from all calorimeter cells, and corrected for the jet energy scale and for the transverse momenta of reconstructed muons.

Scalar LQ Monte Carlo samples with masses from 140 GeV to 320 GeV have been generated with PYTHIA [9] using the CTEQ6L1 [10–12] parton density functions (PDFs). Two processes are generated: $q\bar{q} \rightarrow LQ\bar{LQ}$ (dominant for LQ masses above 100 GeV) and $g\bar{g} \rightarrow LQ\bar{LQ}$ [13]. The LQs are treated as resonances and their isotropic decay mode is to a u quark and an electron. The PYTHIA code has therefore been slightly modified to allow that one of the LQs decays into a d quark and a neutrino. The $LQ \rightarrow ql$ vertex depends on the Yukawa coupling λ which affects the width of the LQ. We have taken λ equal to the electromagnetic coupling $\sqrt{4\pi\alpha}$. The next-to-leading order (NLO) cross section of scalar LQ pair production has been calculated in Ref. [14]. To generate the vector leptoquarks, the model described in Ref. [15] and implemented in COMHEP [16] is used. In this model, the leading order (LO) cross section depends on the LQ mass and on the anomalous couplings of the LQ to the gluon, κ_G and λ_G . In the following, three types of couplings have been considered: “MC” coupling $\{\kappa_G = 1, \lambda_G = 0\}$, “YM” coupling $\{\kappa_G = 0, \lambda_G = 0\}$ and “MM” coupling $\{\kappa_G = -1, \lambda_G = -1\}$. We have generated pairs of vector leptoquarks with masses between 200 GeV and 480 GeV that decay, as in the scalar LQ case, into an electron and a quark or into a neutrino and a quark, and we have also used a $\lambda = \sqrt{4\pi\alpha}$.

The main SM backgrounds relevant to these final states are the associated production of jets with Z/γ^* or W boson and top quark pairs in dilepton or semi-leptonic channels. Less important contributions come from $Z/\gamma^* \rightarrow \tau\tau$ ($\tau \rightarrow e$), single top quark decaying into e or τ , and diboson final states including jets. Most of the samples were generated with ALPGEN [17] interfaced with PYTHIA for parton showering and hadronization. Exceptions are the diboson and single top processes, which were generated with the PYTHIA and the SINGLETOP [18] event generators, respectively. The PDFs used are CTEQ6L1. The ALPGEN inclusive W/Z production cross section is normalized to the NLO theoretical prediction using K-factors derived by comparing the LO and NLO cross sections in MCFM [19]. All the SM generated backgrounds are normalized to the integrated luminosity of data sample.

Signal and background Monte Carlo samples are processed through a GEANT-based [20] simulation of the DØ detector and the same reconstruction program as used for the collider data. To model the effects of detector noise and multiple $p\bar{p}$ interactions, each Monte Carlo event is overlaid with a data event from a random $p\bar{p}$ crossing. Monte Carlo samples pass the same selection criteria as the data samples. But since the efficiency of these selections is different for data and for Monte Carlo, efficiency corrections are applied to the simulated events: the trigger probability

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¹⁰ The pseudorapidity η is equal to $-\ln[\tan(\theta/2)]$ where θ is the polar angle relative to the proton beam direction. ϕ is the azimuthal angle in the plane transverse to the beam direction.

¹¹ The fraction of energy in an annular isolation cone of radius $0.2 < \mathcal{R} < 0.4$ must be less than 15% of the energy in the core cone of radius $\mathcal{R} < 0.2$, where $\mathcal{R} = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.

(η and p_T -dependent efficiencies for the chosen single electron triggers), a correction for the efficiencies of the jet selection, an η and ϕ dependent correction of the electron selection efficiency, and a correction to reproduce the luminosity profile of the data and the distribution along beam axis of the event primary vertex.

In the $eejj$ analysis, events are selected with at least two isolated electrons satisfying *tight* identification criteria, with $p_T \geq 25$ GeV and at least one of the two detected in the central part of the calorimeter ($|\eta| \leq 1.1$). The selected events must also contain one or more jets with $p_T \geq 25$ GeV and $|\eta| \leq 2.5$. In addition to the main SM backgrounds described above, an instrumental background consists of multijet processes (MJ), and is due to the misidentification of jets as electrons. This contribution is extracted from data. A specific sample containing events with two “fake” electrons and at least one additional jet, where a “fake” electron is an isolated cluster in the calorimeter with the usual EM fraction value for a loose electron but shower shape conditions relaxed, is used to reproduce the shapes of the kinematical distributions. The normalization of the total expected background to the number of data events in two regions of the M_{ee} spectrum ($50 < M_{ee} \leq 80$ GeV and $80 < M_{ee} \leq 102$ GeV) gives the MJ and $Z/\gamma^* + \text{jets}$ sample contributions. The $t\bar{t}$ and diboson contributions are normalized to the luminosity. Two normalization factors are extracted and further used to determine the number of background events in the sample obtained when the requirement of a second jet with $p_T \geq 25$ GeV is added.

After the requirements of two electrons and two jets, 448 events remain in the data sample, with 449 ± 13 predicted background events of which 91% originates from the $Z/\gamma^* \rightarrow e^+e^-$ samples. The dielectron invariant mass M_{ee} and the transverse scalar energy S_T (see Fig. 1), defined as the scalar sum of the p_T of the two electrons and the two highest E_T jets, are used as discriminant variables in this analysis. Most $Z/\gamma^* \rightarrow e^+e^-$ events are concentrated around the mass of the Z boson ($80 < M_{ee} < 102$ GeV), and the multijet contribution populates the region $S_T < 300$ GeV. To suppress as much background as possible while minimizing any reduction of signal acceptance, the selections on the M_{ee} and S_T variables have been optimized. For different sets of requirements on these variables, we combine the numbers of expected signal and background events, and their uncertainties, from the bins of the average electron-jet invariant mass distribution to calculate the expected upper limit on the cross section at 95% C.L. We used a modified frequentist CLs method, based on a likelihood ratio as described in Ref. [21]. The effects of systematic uncertainties on the signal and background, taking into account correlations, are included in the resulting limits. The best sensitivity is obtained for $M_{ee} > 110$ GeV and $S_T > 400$ GeV. After all selections, no data events remain, for an expected SM background of $1.51 \pm 0.12(\text{stat}) \pm 0.04(\text{syst})$ events (see Table 1). The acceptance for a scalar LQ with a mass between 250 GeV and 300 GeV varies between 20% and 23%. The acceptances for the vector LQs are similar.

In the $evjj$ analysis we select events containing exactly one isolated electron satisfying *tight* identification criteria with $p_T \geq 25$ GeV and $|\eta| < 1.1$, and with $\cancel{E}_T \geq 35$ GeV. The selected events must also contain at least two high p_T jets with $|\eta| < 2.5$, with the leading jet having $p_T \geq 40$ GeV and the second leading jet having $p_T \geq 25$ GeV. A veto on a second tight electron with $|\eta| < 2.5$ guarantees that there is no overlap with the $eejj$ analysis. Multijet processes again contribute to an instrumental background. A fake electron could be present due to misidentification of one jet, and the \cancel{E}_T could be due to the resolution of the jet energy measurement. Events with ≥ 3 jets can thus be reconstructed as $evjj$ events. In these events, the \cancel{E}_T tends to point in the direction of the fake electron. A triangular cut in the $\Delta\phi(e, \cancel{E}_T) - \cancel{E}_T$ plane is

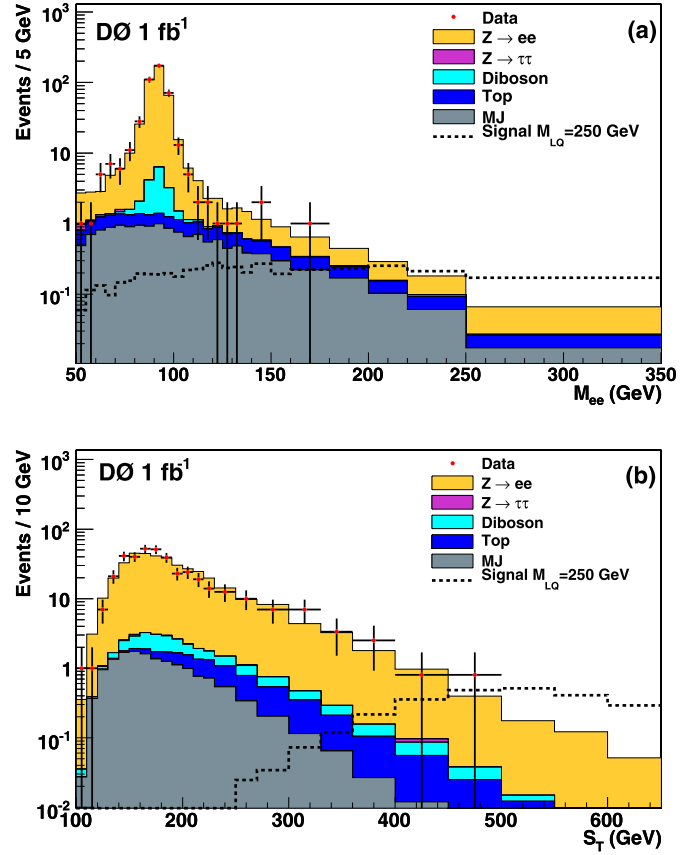


Fig. 1. Distributions of (a) the dielectron invariant mass M_{ee} and (b) S_T for events with ≥ 2 jets. The signal for a scalar LQ with $M_{LQ} = 250$ GeV has been superimposed. (For interpretation of the references to color in this figure, the reader is referred to the web version of this Letter.)

Table 1

$eejj$ analysis: number of events in each sample after all selections (see text). The two errors on the total expected background correspond to the statistical and systematical uncertainties. The uncertainties quoted on each individual background are only statistical.

Sample	Number of events
Data	0
Total expected background	$1.51 \pm 0.12 \pm 0.04$
$Z/\gamma^* + \text{jets}$	1.11 ± 0.10
Multijet	0.10 ± 0.06
Top	0.29 ± 0.01
Diboson	0.01 ± 0.01

applied ($\Delta\phi(e, \cancel{E}_T) \geq \pi - 0.045\cancel{E}_T$ with \cancel{E}_T in GeV) to minimize this background.

In order to model the multijet contribution, a sample containing events with one “fake” electron and ≥ 2 additional jets is created. The number of multijet background events is computed using the method described in Ref. [22]. Two samples of events are used, the first one contains events with a *loose* electron and the second one, which is a subsample of the first one, is composed of events with a *tight* electron. Using the number of events in these two samples together with the efficiencies for a real and a “fake” electron to pass the likelihood condition, referred to as ϵ_{SM} and ϵ_{MJ} respectively, we can determine the number of MJ events. We measure ϵ_{SM} as the ratio of the number of Monte Carlo events which pass the likelihood condition over the number of Monte Carlo events which fail it and correct for differences between data and simulation. We measure ϵ_{MJ} directly from data

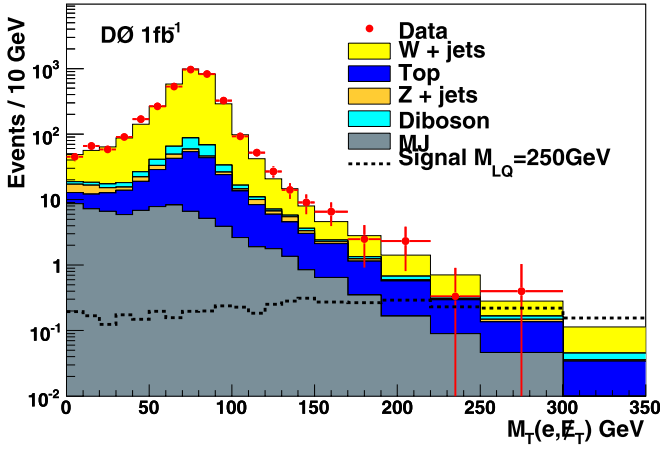


Fig. 2. Distribution of the variable $M_T(e, \cancel{E}_T)$ when the cuts used for the background normalization are applied. The signal for a scalar LQ sample with $M_{LQ} = 250$ GeV has been superimposed. (For interpretation of the references to color in this figure, the reader is referred to the web version of this Letter.)

Table 2

$evjj$ analysis: number of events in each sample after all selections (see text). The two errors correspond to the statistical and systematic uncertainties.

Sample	Number of events
Data	8
Total expected background	$9.8 \pm 0.8 \pm 0.8$
W + jets	$5.0 \pm 0.7 \pm 0.3$
Top	$3.29 \pm 0.07 \pm 0.26$
Z/ γ^* + jets	$40.15 \pm 0.06 \pm 0.01$
Diboson	$0.48 \pm 0.05 \pm 0.04$
Multijet	$40.9 \pm 0.2 \pm 0.07$

assuming that the low \cancel{E}_T region ($\cancel{E}_T \leq 10$ GeV) is dominated by the multijet background after subtracting a small contribution of real electrons determined from Monte Carlo. The number of Monte Carlo W + jets events is normalized to data within a range of the transverse invariant mass of the electron and the \cancel{E}_T where the expected number of LQ s is very small: $M_T(e, \cancel{E}_T) \leq 100$ GeV. There is good agreement between data and expected SM background both in number of events and in the shape of the distributions. The $M_T(e, \cancel{E}_T)$ distribution is shown in Fig. 2 with the signal for a scalar LQ sample for $M_{LQ} = 250$ GeV superimposed. The number of data events that pass the selection criteria is equal to 3563 which is in good agreement with the total expected background of 3549 ± 68 events, of which 87% come from W + jets events. A cut $M_T(e, \cancel{E}_T) \geq 130$ GeV strongly reduces this background. Other discriminants are the p_T distributions of the decay products of the two LQ s. We determined the best p_T cuts as described in the $eejj$ analysis, but using the S_T distribution, where S_T is the sum of the p_T of the electron, the p_T of the two leading jets, and \cancel{E}_T . The best expected cross section limits are obtained for a cut of 80 GeV on both the p_T of the electron and the \cancel{E}_T , and the cuts $p_T(\text{leading jet}) > 40$ GeV and $p_T(\text{second jet}) > 25$ GeV. After all selections, 8 events remain, for an expected SM background of $9.8 \pm 0.8(\text{stat}) \pm 0.8(\text{syst})$ events (see Table 2). The acceptances are similar for scalar or vector LQ s. They range from 18.5% to 20% for a LQ mass varying between 250 GeV to 300 GeV.

In Fig. 3, the distributions of the masses $M(e, \text{jet})$ and $M_T(\cancel{E}_T, \text{jet})$ are shown. The signal for a scalar LQ sample for $M_{LQ} = 250$ GeV has been superimposed. The agreement is good between data and the SM expectations, both in number of events and in the shape of the distributions.

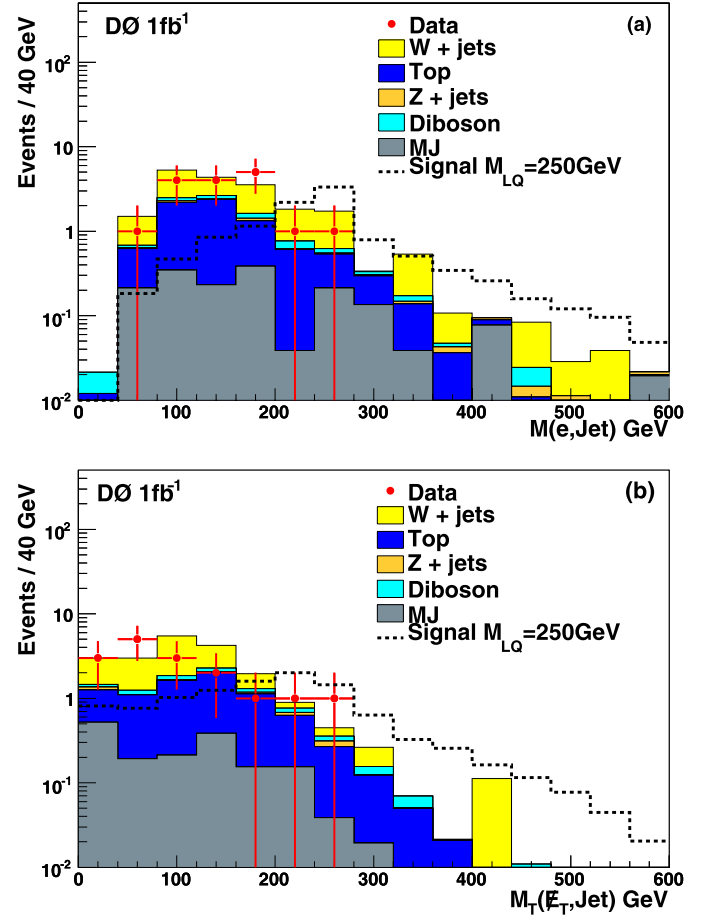


Fig. 3. Distributions of (a) $M(e, \text{jet})$ and (b) $M_T(\cancel{E}_T, \text{jet})$ after all cuts. There are two entries per event. The signal for a scalar LQ sample with $M_{LQ} = 250$ GeV has been superimposed. (For interpretation of the references to color in this figure, the reader is referred to the web version of this Letter.)

Table 3

Summary of systematic uncertainties in %.

Final state Source	$eejj$		$evjj$	
	SM	Signal	SM	Signal
JES	+1.7–2.0	+0.1–0.5	+1.8–1.3	+0.9–0.5
Jet resolution			+1.5–0.5	
Jet ID	0.4	0.7	0.2	0.7
EM ID	0.2	8	1.4	4.2
Luminosity		6.1	2.5	6.1
PDF (acceptance)		5		5
Background norm.	1.2			
SM uncertainties	1.2			
Background norm.			4.4	
SM uncertainties			7.6	

The values of the systematic uncertainties are summarized in Table 3. Most of them are determined by varying parameters by ± 1 standard deviation. This includes the jet energy scale (JES), the jet energy resolution and the jet identification efficiency (Jet ID). The systematic uncertainty from the correction of the electron identification efficiency (EM ID) is evaluated from the uncertainty on the Monte Carlo/data correction factors and by choosing another parametrization of the correction. Other systematics uncertainties affect the luminosity, or are computed by measuring the effect of the PDF choice on the signal acceptances using a different PDF set (20-eigenvector basis CTEQ6.1M NLO PDF). The uncertain-

Table 4Observed cross section limits (in fb) (95% C.L.) for a scalar LQ and vector LQ with different couplings as a function of the branching fraction β .

M_{LQ} (GeV)	240	260	280	300	320	340	360	380	400	420	440	460	480
β	σ (fb) scalar LQ												
0.5	26	24	21	20	19								
1.0	16	15	14	13	13								
β	σ (fb) vector LQ “MC” coupling												
0.5			22	21	20	18	17	17					
1.0			14	14	13	13	13	12					
β	σ (fb) vector LQ “YM” coupling												
0.5				18	18	17	17	17	16	16	15		
1.0				13	13	12	12	12	12	12	12		
β	σ (fb) vector LQ “MM” coupling												
0.5					18	18	17	17	16	16	15	16	16
1.0					13	12	12	12	12	12	12	12	12

ties due to the propagation into the analyses of uncertainties on the parameters used in the background normalization are referred as background normalization in Table 3. The SM uncertainties are the combined relative uncertainties on the expected background due to uncertainties on the cross sections of the SM processes and to different modeling of jet radiation in the $W + \text{jets}$ process. The uncertainties that are shown on the same row are treated as correlated in the determinations of the limits.

No deviations from the SM predictions were observed in our data in either the $eejj$ final state or in the $evjj$ final state and for each individual channel we determined cross section limits on the pair production of a first-generation scalar LQ at 95% C.L. The results are shown in Fig. 4 where the expected and observed cross section limits measured in the $eejj$ and $evjj$ final states are displayed as a function of the LQ mass, assuming $\beta = 1$ and $\beta = 0.5$ respectively. On the same figure the scalar LQ pair production NLO cross sections, calculated for different values of the renormalization and factorization scales ($\mu = M_{LQ}$, $M_{LQ}/2$ and $2M_{LQ}$) are also shown.

In DØ analysis [23], using a sample of 2.5 fb^{-1} of data with acoplanar jets and missing transverse energy, a search for the pair production of first generation scalar leptoquarks both decaying in νq has shown no evidence of this production. We combined these three analyses to determine expected and observed cross section limits as a function of β and M_{LQ} . We used the modified frequentist CLs method referenced in the $eejj$ analysis and the JES, PDF and luminosity systematics uncertainties are treated as correlated errors. As an example, the values of the observed cross section limits are given in Table 4 for $\beta = 1$ and $\beta = 0.5$. For each value of β , the limit is the LQ mass value where the experimental cross section limit and the theoretical cross section are equal. The expected and observed mass limits for factorization and renormalization scales μ equal to M_{LQ} are summarized in Table 5. They are shown in the β - M_{LQ} plane in Fig. 5 together with the limits obtained in each final state analysis. The theoretical uncertainty on the observed mass limit, reflecting the PDF, normalization and factorization scale uncertainties, is also shown.

To compute the limit on vector LQ cross sections, as the vector and scalar LQ acceptances are very similar, we use the selections which have been found optimal in the search for a scalar LQ . The expected and observed cross section limits for each of the two final states $eejj$ and $evjj$, assuming $\beta = 1$ and $\beta = 0.5$ respectively, are shown in Fig. 6 as a function of the LQ mass. The vector LQ pair production LO cross sections are also shown, for each of the three couplings. They are calculated for different values of the renormalization and factorization scales $\mu = M_{LQ}$, $M_{LQ}/2$ and $2M_{LQ}$. We combine these results to get expected and observed cross section

Table 5Expected and observed mass limits (in GeV) for a scalar LQ and vector LQ with different couplings as a function of the branching fraction β , assuming for factorization and renormalization scales $\mu = M_{LQ}$.

β	Scalar LQ		“MM” coup.		“YM” coup.		“MC” coup.	
	exp.	obs.	exp.	obs.	exp.	obs.	exp.	obs.
0.02	218	216						
0.04	220	220						
0.06	222	225						
0.08	226	231						
0.1	229	235	417	420	365	368	293	302
0.2	244	254	440	441	387	390	320	327
0.3	256	268	452	453	399	402	337	342
0.4	265	276	459	460	407	409	346	351
0.5	273	284	463	464	413	415	353	357
0.6	280	289	466	467	417	419	357	361
0.7	285	293	469	469	420	423	361	365
0.8	288	296	470	470	422	424	363	367
0.9	293	297	471	471	424	425	366	369
1.0	297	299	472	472	424	425	367	370

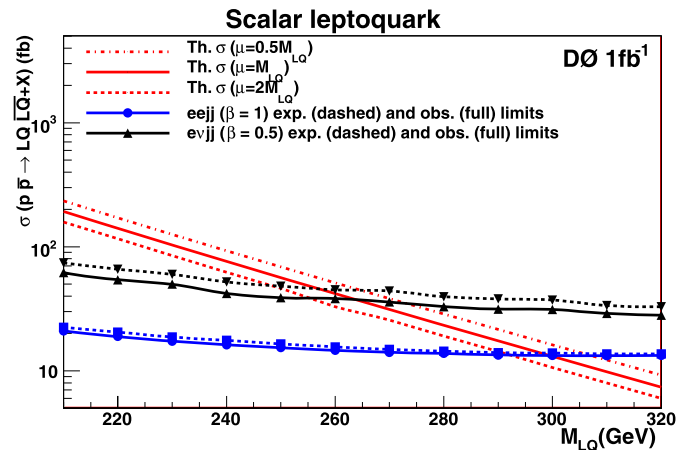


Fig. 4. Cross sections as a function of the LQ mass for a scalar leptoquark. The NLO theoretical cross sections are drawn for different values of the renormalization and factorization scales: M_{LQ} (solid line), $M_{LQ}/2$ (dot-dashed line) and $2M_{LQ}$ (dashed line). The horizontal lines correspond to the expected cross section limits (squares and downward triangles) and the observed cross section limits (circles and upward triangles), both at the 95% C.L., in the $eejj$ channel (blue curves) assuming $\beta = 1$ and in the $evjj$ channel (black curves) assuming $\beta = 0.5$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this Letter.)

limits as a function of β . The values of these limits obtained for $\beta = 1$ and $\beta = 0.5$ are given in Table 4. The expected and observed

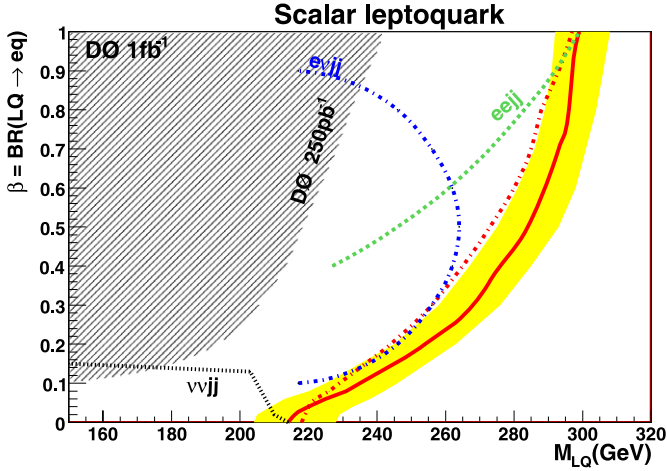


Fig. 5. Observed (red full line) and expected (red dot-dashed line) mass limits at the 95% C.L. in the β versus LQ mass plane for the pair production of first-generation scalar leptoquarks and the nominal signal cross section hypothesis ($\mu = M_{LQ}$). The regions to the left of the curves are excluded. The band, around the observed mass limit curve, shows the effect of the theoretical uncertainty (see text) on the observed exclusion. The observed limits found individually using each of the three final states are shown for the nominal cross section hypothesis ($\mu = M_{LQ}$) and the hatched area is the part of the plane previously excluded by the DØ Collaboration with a lower luminosity and for the minimal cross section hypothesis ($\mu = 2M_{LQ}$). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this Letter.)

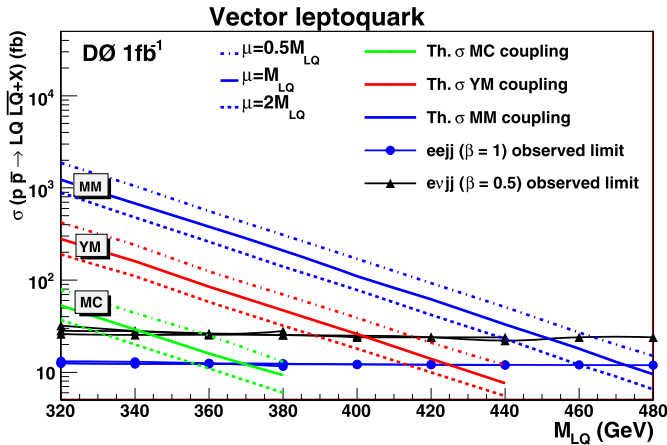


Fig. 6. Cross sections as a function of the LQ mass for a vector leptoquark and the three couplings “MC”, “YM” and “MM”. The LO theoretical cross sections are drawn for different values of the renormalization and factorization scales: M_{LQ} (solid line), $M_{LQ}/2$ (dot-dashed line) and $2M_{LQ}$ (dashed line). The horizontal lines correspond to the observed cross section limits at the 95% C.L. in the $eejj$ channel (circles on blue curves) assuming $\beta = 1$ and in the $evjj$ channel (triangles on black curves) assuming that $\beta = 0.5$. Small differences in acceptance for different couplings result in marginally different limits shown as the quasi-overlapping curves for each of the channels. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this Letter.)

mass limits for a factorization and renormalization scales equal to M_{LQ} are summarized in Table 5. They are shown in the β – M_{LQ} plane in Fig. 7 for the three couplings. The hatched areas show the effect of the theoretical uncertainties on the observed exclusions.

In this analysis of the DØ Run II dataset corresponding to an integrated luminosity of about 1 fb^{-1} , we have excluded a first-generation scalar LQ with mass varying between 216 GeV for $\beta = 0.02$ to 299 GeV for $\beta = 1$ assuming $\mu = M_{LQ}$. For $\mu = 2M_{LQ}$, the mass limits range from 206 GeV to 292 GeV. These results improve bounds given in previous LQ searches at Tevatron [2,3] by

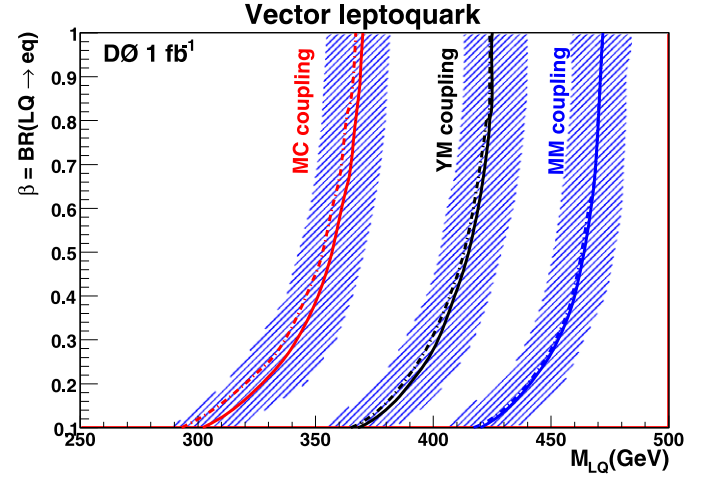


Fig. 7. Observed (full lines) and expected (dot-dashed lines) mass limits at the 95% C.L. in the β versus LQ mass plane for the pair production of first-generation vector leptoquarks. They are shown for different couplings (from left to right: the “MC” coupling, the “YM” coupling and the “MM” coupling) and for the nominal cross section hypothesis ($\mu = M_{LQ}$). The regions to the left of the curves are excluded. The hatched bands show the effect of the theoretical uncertainty (see text) on the observed exclusions.

$\simeq 50$ GeV. We have also excluded vector LQ s for different couplings. As an example for $\beta = 0.5$ and $\mu = M_{LQ}$, lower limits on vector leptoquark masses, varying from 357 GeV to 464 GeV, are set for different couplings. These mass limits are the most constraining found in a direct search for first-generation leptoquarks to date.

Acknowledgements

We thank the staffs at Fermilab and collaborating institutions, and acknowledge support from the DOE and NSF (USA); CEA and CNRS/IN2P3 (France); FASI, Rosatom and RFBR (Russia); CNPq, FAPERJ, FAPESP and FUNDUNESP (Brazil); DAE and DST (India); Colciencias (Colombia); CONACyT (Mexico); KRF and KOSEF (Korea); CONICET and UBACyT (Argentina); FOM (The Netherlands); STFC and the Royal Society (United Kingdom); MSMT and GACR (Czech Republic); CRC Program, CFI, NSERC and WestGrid Project (Canada); BMBF and DFG (Germany); SFI (Ireland); The Swedish Research Council (Sweden); CAS and CNSF (China); and the Alexander von Humboldt Foundation (Germany).

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